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Statistical analysis of relationships between road accidents involving personal injury and meteorological variables in Hungary

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Abstract— Public opinion and certain human meteorological communications assume close relationship between meteorological variations and human conditions, especially the development of traffic accidents. This paper presents a detailed statistical analysis between domestic road accidents involving personal injury and relevant meteorological conditions for the period of 1990–2010 in Hungary. Approximately 431 thousand accidents were analyzed based on official statistical data. In general, a significant but weak interrelation was found between the absolute change – calculated from the previous day – of road traffic accidents involving personal injury and meteorological conditions. The results of multivariate linear regression analysis show that meteorological variations affected only nearly four percent of the variation of accidents relative to traffic. We demonstrated, however, that together with the significant variation of certain meteorological parameters, the number of accidents also significantly varies. Days with extreme meteorological variations explain the development of accidents in 9.8 percent, while in the case of days with non-extreme variations, this value was only 2.6 percent.

Key-words: road accidents with personal injury, multivariate regression, main component analysis, discriminant analysis, climate variation

1. Introduction

There is little scientifically grounded understanding of the effect of climatic variations on everyday living conditions, notwithstanding the numerous studies based on rather limited evidence – looking mainly at the relationship of accident rescue and weather (*Andersson* and *Chapman,* 2011; *Edwards*, 1999; *Jaroszweski et al*., 2010; *Suarez et al*., 2005). In spite of this, public opinion and certain human meteorological communications assume close relationship between meteorological variations and human conditions, especially the development of traffic accidents. During the past fifty years, significant results were achieved in the field of the investigation of relationship between road traffic conditions and meteorological parameters. The research activity carried out so far focused only on selected meteorological variables (*Sándor*, 2013). Present paper is aimed at exploring, as far as possible, complex statistical interrelations between road accidents involving personal injury and related meteorological parameters in Hungary.

Due to relatively advantageous circumstances, an opportunity presented itself to perform the joint statistical analysis of all domestic road traffic accidents involving personal injury between 1990 and 2010 (source: KSH data collection, data provider: police OSAP1009) and the relatively detailed data of selected meteorological observatory sites of the Hungarian Meteorological Service (Budapest, Pécs, Szeged, Debrecen, Szombathely, Győr, Nagykanizsa, and Siófok) for the same period. Nearly 13 million data of the approximately 431 thousand accidents were analyzed in details. The statistical analyses were done mostly on the basis of daily averages of the originally hourly data and absolute changes calculated from the previous day.

The key studies were completed with the temperature data of the eight meteorological observatory stations, the measured values of precipitation, wind speed, air pressure, relative humidity of the first five stations, and the average values of cloud cover data, as well as the daily average values of road traffic accidents involving personal injury and partially determined by estimation values for traffic on account of absent factual data. Beyond the interrelations between variations in meteorological conditions and the totality of accidents, the analysis touched upon the study of relations among key accident situations and locations.

2. Relationship between traffic accidents and complex variations of meteorological conditions

In general, it can be concluded, that there is significant but weak interrelation between the absolute change – calculated from the previous day – of road traffic accidents involving personal injury and meteorological conditions. The completed multivariate linear regression analysis shows that climatic variations affected only nearly four percent the variation of accidents relative to traffic as summarized in *Table 1* and *Fig. 1*.

Among the analyzed meteorological variations, the variation of precipitation patterns (1.9% points, nearly half of the total impact) had the most significant impact on the development of accidents, followed by temperature variation (0.7% points). Besides the aforementioned components, the variation of cloud cover and relative humidity influenced the development of accidents to 0.5 percentage points, while air pressure variation to 0.4 percentage points. The impact of wind speed was not statistically significant.

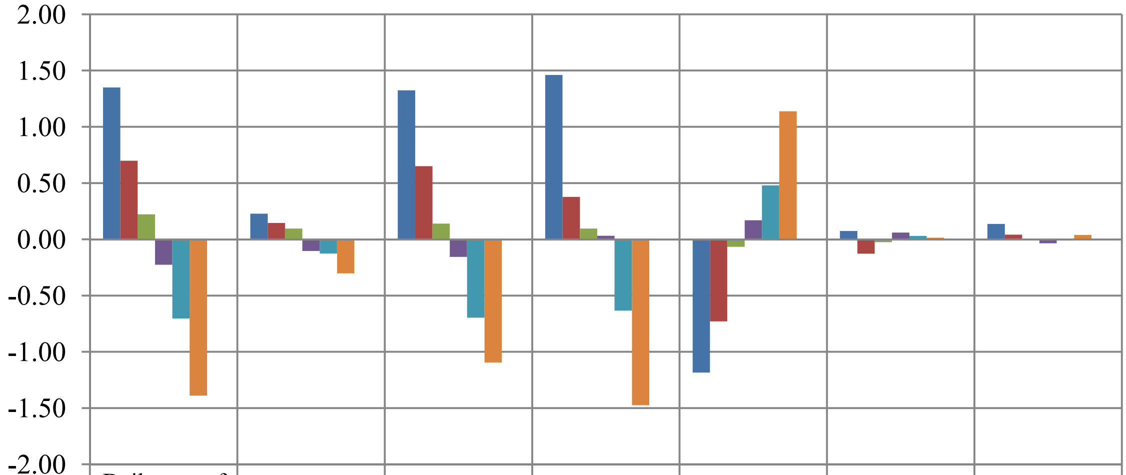
*Table 1.*Multivariate regression interrelations of daily variation of accidents (dependent variable) for estimated traffic between 1990 and 2010 with daily meteorological variation indicators (independent variables), (Stepwise method)

Model summary*									
Model	R	R-squared	Adjusted R-squared	Std. error of the estimate	Change statistics				
					R-squared Change	F change	df1	df2	Sig. F change
1	0.137[a]	0.019	0.019	0.59959	0.019	147.540	1	7668	0.000
2	0.162[b]	0.026	0.026	0.59738	0.007	57.832	1	7667	0.000
3	0.177[c]	0.031	0.031	0.59585	0.005	40.217	1	7666	0.000
4	0.191[d]	0.036	0.036	0.59434	0.005	40.071	1	7665	0.000
5	0.199[e]	0.040	0.039	0.59337	0.003	25.996	1	7664	0.000

[*] Dependent variable: Daily variation of the number of accidents per estimated traffic
[a] Predictors: (constant), variation of daily mean precipitation amount
[b] Predictors: (constant), variation of daily precipitation amount, variation of daily mean temperature
[c] Predictors: (constant), variation of daily mean precipitation amount, variation of daily mean temperature, variation of daily mean cloud cover
[d] Predictors: (constant), variation of daily mean precipitation amount, variation of daily mean temperature, variation of daily mean cloud cover, variation of daily mean relative humidity
[e] Predictors: (constant), variation of daily mean precipitation amount, variation of daily mean temperature, variation of daily mean cloud cover, variation of daily mean relative humidity, variation of daily mean air pressure

Besides the diverse significance of climatic component variations, their direction of effect was also differentiated (*Fig. 1*).

In general – regarding the measured interrelations, the increase of the amount of precipitation, temperature, and relative humidity, the thinning of the cloud cover and the decrease of the air pressure resulted in an increasing number of accidents. Resulting from the foregoing, opposite meteorological processes impacted on or became characteristic of the moderation of accidents. Therefore, nearly parallel with the decrease of precipitation, temperature, and relative humidity, and with the increase of cloud cover and the rise of air pressure, the number of traffic accidents involving personal injury decreased.



	Daily var. of the number of accidents for estimated traffic [accident / hundred thousand vehicles]	Var. of daily mean temperature [°C]	Var. of daily mean precipitation amount [mm]	Var. of daily mean relative humidity [% points]	Var. of daily mean air pressure [hPa]	Var. of daily mean cloud cover [okta]	Var. of daily mean wind speed [m/s]
1.0 – X increase	1.35	0.23	1.32	1.46	-1.19	0.07	0.14
0.5 – 1.0 increase	0.70	0.15	0.65	0.38	-0.73	-0.13	0.04
0.0 – 0.5 increase	0.22	0.10	0.14	0.10	-0.07	-0.03	0.00
0.0 – 0.5 decrease	-0.23	-0.10	-0.16	0.03	0.17	0.06	-0.04
0.5 – 1.0 decrease	-0.70	-0.13	-0.70	-0.63	0.48	0.03	-0.01
1.0 – X decrease	-1.39	-0.30	-1.10	-1.48	1.14	0.01	0.04
Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Fig 1. Daily variation of average values of key meteorological features and of accidents involving personal injury per estimated traffic, calculated from the previous day by categorized values of daily variation of accidents between 1990 and 2010.

Analyses concluded with indicators expressing the daily variation of accidents (not standardized with traffic) and with variants (estimated factor and discriminant function values) obtained from multivariate statistical (factor and discriminant) analysis of the original meteorological indicators led to results almost perfectly identical with the above-mentioned findings.

In contrast with this interrelation, that can be considered generally weak, there are significant differences in the relationship of significantly differing components, types, and categories according to the content and factors, direction and intensity of meteorological variations – separated with multivariate statistical procedures (factor, cluster, and discriminant analysis) – with traffic accidents involving personal injury.

The score of factor analysis of daily meteorological variations represents 87.5% of the variance of the original variants with four relatively well identifiable components (variation of cloud cover, temperature, precipitation, and wind force), and these components well reflect the variation of relative humidity and air pressure, as well (*Table 2*).

Table 2. Scores of key components and factor analysis of indicators representing the absolute variation of meteorological features calculated from the previous day, for days between 1990 and 2010

Component Matrix					
	Component 1	**Component 2**	**Component 3**	**Component 4**	**Communalities**
Variation of daily mean temperature	–0.001	0.787	–0.492	–0.110	0.874
Variation of daily mean precipitation amount	0.714	–0.145	0.246	–0.588	0.936
Variation of daily mean wind speed	0.279	0.557	0.738	0.149	0.956
Variation of daily mean air pressure	–0.671	–0.498	0.22	0.082	0.753
Variation of daily mean humidity	0.746	–0.468	–0.254	0.037	0.842
Variation of daily mean cloud cover	0.787	–0.046	–0.056	0.515	0.889
Extraction sums of squared Loadings in % of variance	36.87	23.68	16.07	10.88	
Extraction sums of squared Loadings in cumulative %	36.87	60.55	76.62	87.50	
Rotated Component Matrix					
	Component 1	**Component 2**	**Component 3**	**Component 4**	**Communalities**
Variation of daily mean temperature	–0.131	**0.914**	–0.150	0.007	0.874
Variation of daily mean precipitation amount	0.181	–0.008	**0.943**	0.118	0.936
Variation of daily mean wind speed	0.041	0.079	0.096	**0.969**	0.956
Variation of daily mean air pressure	–0.403	–0.667	–0.328	–0.195	0.753
Variation of daily mean humidity	0.735	–0.091	0.445	–0.310	0.842
Variation of daily mean cloud cover	**0.919**	0.069	0.068	0.186	0.889
Extraction sums of squared Loadings in % of variance	26.64	21.66	20.51	18.69	
Extraction sums of squared Loadings in cumulative %	36.87	60.55	76.62	87.50	

Extraction method: principal component analysis.
Rotation Method: varimax with Kaiser normalization.

The separation of types, essentially different in the content, structure, and direction of climatic variations, was completed with the so-called K-mean cluster analysis of rotated components obtained from factor analysis, in five variations, incrementally expanding the number of possible types (clusters). The applied procedure resulted in typologies of 7, 10, 15, 20, and 25 numbers of element, the reliability and final content of which were tested partially with four climate change components from factor analysis, and partially with discriminant analyses run on the original variants (*Table 3*).

Table 3. Tests of equality of group means

	Wilks' lambda	F	df1	df2	Sig.
Daily meteorological variations, 25 clusters					
Variation of daily mean precipitation amount	0.208	1215	24	7645	0.00
Variation of daily mean cloud cover	0.313	698	24	7645	0.00
Variation of daily mean wind speed	0.317	688	24	7645	0.00
Variation of daily mean temperature	0.394	491	24	7645	0.00
Variation of daily mean humidity	0.413	452	24	7645	0.00
Variation of daily mean air pressure	0.487	336	24	7645	0.00

Although both approaches hold statistically significant classifications, corresponding to approaches searching less types, the 25-cluster solution represents more reliable and detailed diversity of day-to-day climatic variations of the period, both in total and in the various components. The above is confirmed furthermore by the fact, that the discriminant analyses qualified the distribution of daily variations by 25 types to be rather good – namely, cross classification with four components was matched in 96.5%, and with six original meteorological variations it matched 92.8% of the original classification, therefore, it qualified the classification as correct. The minor difference between the scores of cluster analysis and the discriminant analyses is partially due to that factor analysis and discriminant analysis which defined the significance hierarchy of meteorological variation components somewhat differently.

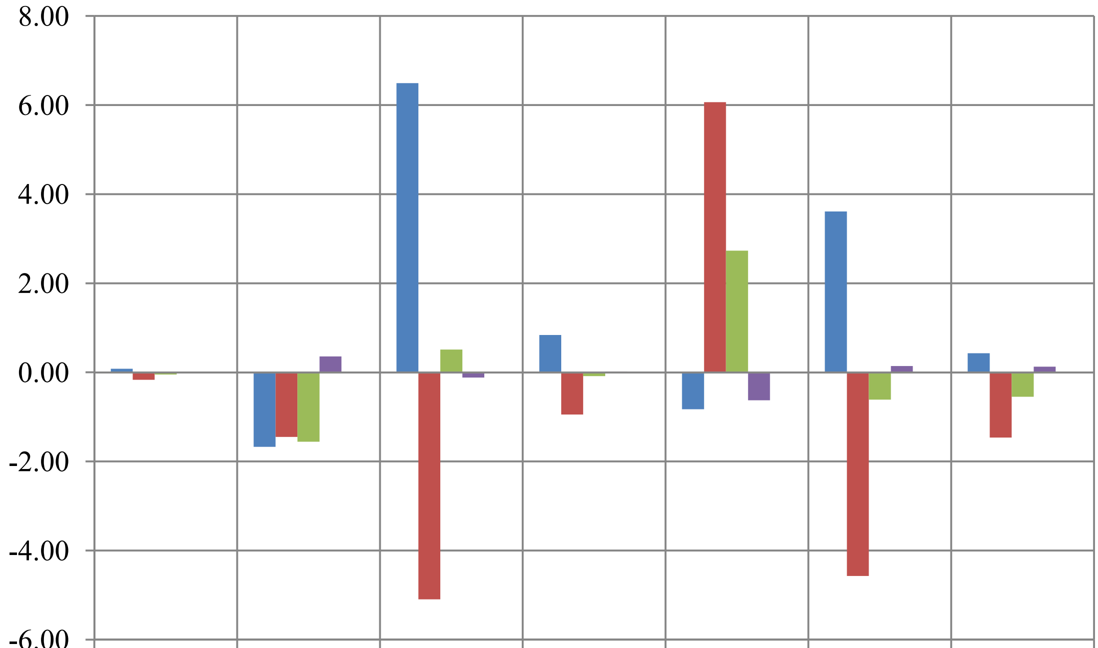
According to discriminant analyses, in the period between 1990 and 2010, the key determinant, the component of day-to-day climatic variations was the development of precipitation patterns (34.3% variance explained), followed by – with nearly identical weight – cloud cover (24.1%), wind force (21.2%), and temperature change (19.7%).

The rather detailed classification offered empirical opportunity to a more aggregate categorization by intensity and directions of multidimensional variations, to the separation of extreme or non-extreme variations considering the general trend, furthermore, to differentiate extremities according to their direction – appearing, rising or moderating, disappearing. The categorization of the 25 clusters was mainly based on the automatic classification (K-mean clustering) of the group average of estimated values of discriminant functions obtained from the discriminant analysis, but the result from the former ones was supplemented by the content analysis of factor values calculated for the clusters and of the original variants. Finally, 5 groups (9 percent of days) of the 25 cluster solution fell in the appearing-rising extremes category, 6 groups (9.7 percent of days) fell in the disappearing-moderating extremes category, and the remaining 14 groups with 81.3 percent of the days of the 20 years form the group of changes not classified as extreme (*Table 4*). The category of extreme changes is, naturally, the result of the pooling of rising and moderating extremes.

Table 4. Group means of rotated components and discriminant functions of groups separated by the direction and intensity of day-to-day meteorological variations

	Rotated factors from factor analysis of day-to-day meteorological variations				**Value of discriminant functions from the discriminant analysis based on rotated factors of the 25-cluster solution of meteorological variations**				**Days**	
	Meteorological variation component				**Discriminant function**				**Number of**	**Distribution of (%)**
	3. Var. of precipi tation amount	**1. Var. of cloud cover**	**4. Var. of wind speed**	**2. Var. of tempe rature**	**1. Var. of daily precipi tation amount**	**2. Var. of daily cloud cover**	**3. Var. of daily wind speed**	**4. Var. of daily tempe rature**		
	Factor score				**Discriminant scores**					
	Group means									
Rising extreme	1.67	0.00	0.72	–0.70	3.71	–0.35	1.16	–0.87	694	9.0
Decreasing extreme	–1.18	–0.61	–0.68	–1.02	–2.60	–1.50	–0.52	–1.83	741	9.7
Extreme variation	0.20	–0.31	0.00	–0.86	0.45	–0.94	0.29	–1.37	1435	18.7
Non-extreme variation	–0.05	0.07	0.00	0.20	–0.10	0.22	–0.07	0.31	6235	81.3
Days total in 1990–2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7670	100.0

(The plus and minus 0.5, and especially, the above and below (plus and minus) 1.0 group means resulting from the standardizing and normalizing procedure applied in the construction of factor values resulting from factor analyses can be clearly regarded as extremes.) Daily variation of the average values of key meteorological features, and of accidents involving personal injury per estimated traffic, calculated from the previous day by extremity of meteorological variation are shown in *Figs. 2, 3.* and *4.*



	Daily var. of accidents for estimated traffic	Var. of daily mean temperature [°C]	Var. of daily mean precipitation amount [mm]	Var. of daily mean wind speed [m/s]	Var. of daily mean air pressure [hPa]	Var. of daily mean relative humidity [% points]	Var. of daily mean cloud cover [okta]
Rising extremes	0.08	-1.67	6.49	0.84	-0.83	3.61	0.43
Moderating extremes	-0.17	-1.45	-5.09	-0.95	6.06	-4.57	-1.46
Extreme variations total	-0.05	-1.56	0.51	-0.08	2.73	-0.61	-0.55
Non-extreme variations total	0.01	0.36	-0.12	0.02	-0.63	0.14	0.13
1990 – 2010 total	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Fig 2. Daily variation of the average values of key meteorological features, and of accidents involving personal injury per estimated traffic, from the previous day calculated by extremity of meteorological variation between 1990 and 2010.

The aggregate categorization of meteorological variations by the intensity and direction of the extremes, according to the prepared statistics, is significant for all meteorological indicators especially for the variation of precipitation, then air pressure, wind speed and temperature, however, not nearly to the extent as in the case of the 25 categories.

Because of the complexity and type richness of climatic variations, it may seem a problematic endeavor to condense in three categories the result of a classification based on four independent components of different significances, because even allowing 25 types will leave significant heterogeneities within the different types (clusters). Despite the above reservations, statistical control examinations qualified the classification as satisfactorily reliable. For example, the discriminant analyses - based on the original variables as well as on the factors formed from these - qualified the conformity of the three-category classification to be correct in 89 percent – pertaining to the same category as the initial classification. In terms of content, the only difference is that reclassifications drew somewhat broader borders for the extremes, and this directly resulted in a lower (down to 72 percent of days) proportion of non-extreme days (*Table 5*).

Table 5. Results of classification

Classification results[b,c]						
Meteorological extremes 1990–2010			**Predicted group membership**			**Total**
			Rising extremes	**Moderating extremes**	**Non-extreme days**	
Original	Count	Rising extremes	602	19	73	694
		Moderating extremes	10	675	56	741
		Non-extreme days	250	460	5525	6235
	%	Rising extremes	86.7	2.7	10.5	100.0
		Moderating extremes	1.3	91.1	7.6	100.0
		Non-extreme days	4.0	7.4	88.6	100.0
Cross-validated[a]	Count	Rising extremes	601	19	74	694
		Moderating extremes	10	674	57	741
		Non-extreme days	252	460	5523	6235
	%	Rising extremes	86.6	2.7	10.7	100.0
		Moderating extremes	1.3	91.0	7.7	100.0
		Non-extreme days	4.0	7.4	88.6	100.0

[a] Cross validation is done only for the cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

[b] 88.7% of original grouped cases correctly classified.

[c] 88.6% of cross-validated grouped cases correctly classified.

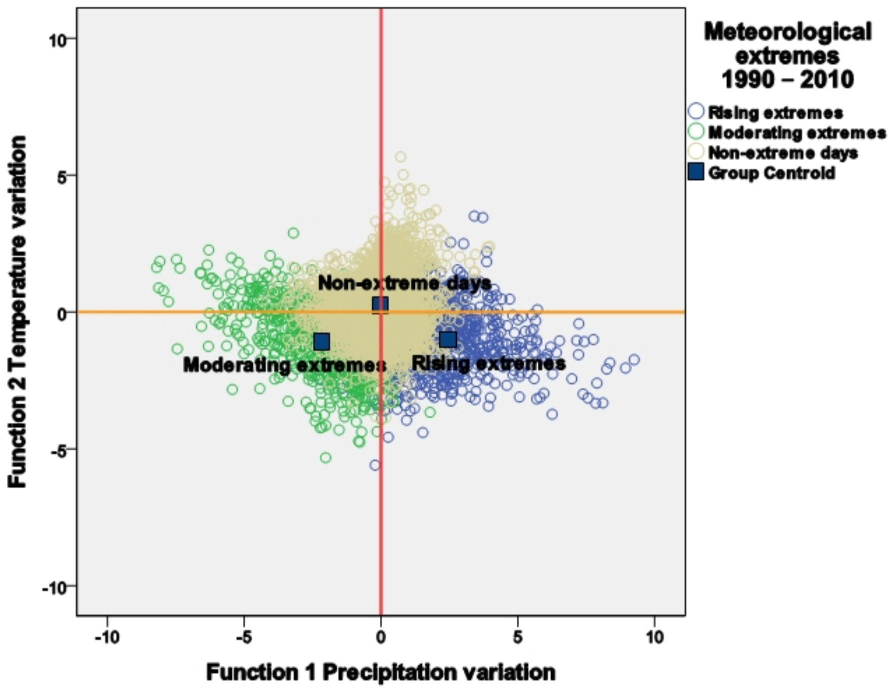


Fig 3. Meteorological extremes for the period 1990–2010 (canonical discriminant functions).

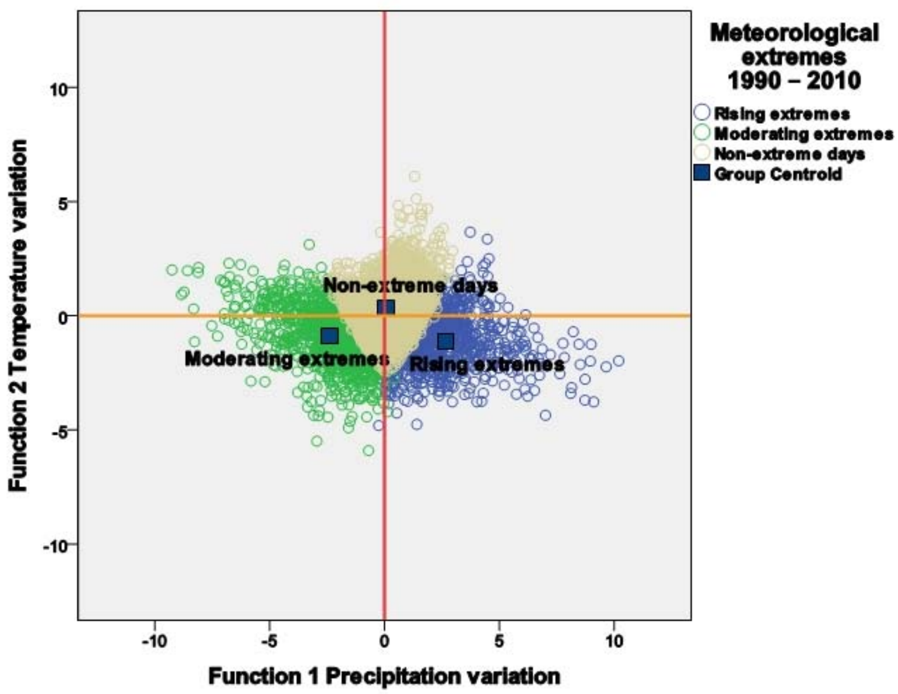


Fig 4. Meteorological extremes for the period 1990–2010 (canonical discriminant functions reclassified).

The grouping of day-to-day meteorological variations by intensity and direction created the opportunity of in-detail analysis of accidents involving personal injury by the indicated categories. The development of multivariate linear regression analysis relation (R-squared) calculated between traffic accidents involving personal injury per estimated traffic and day-to-day variation of meteorological features by meteorological change extremes can be seen in *Fig. 5*.

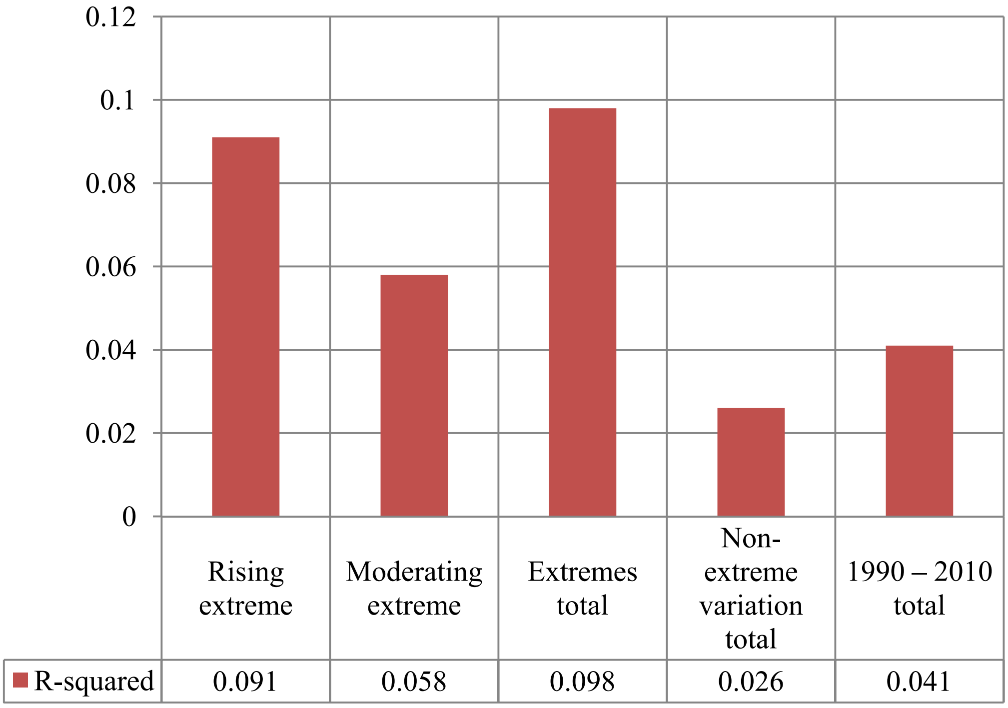


Fig. 5. The development of multivariate linear regression analysis relation (R-squared) calculated between traffic accidents involving personal injury per estimated traffic and day-to-day variation of meteorological features by meteorological change extremes.

Analyses and classifications in the case of days qualified as extreme in meteorological change show marked interrelations between accidents and climatic variations. Moreover, the more intense the variation, the more powerful the correlation formed with the variation (rise or modification) of accidents.

In accordance with the multivariate linear regression calculated between the extreme meteorological change and accident variation, meteorological variations explained already 9.8 percent of accident variation. In contrast, road traffic accidents involving personal injury under non-extreme meteorological variation conditions can only be attributed in 2.6 percent – more than three and half times smaller proportion than in case of extreme variations – to climatic changes from the previous day. Results of stepwise method applied are summarized in *Table 6*.

Among the components of extreme meteorological variation conditions, the variation of accidents (increase or decrease) was most fundamentally affected by the combination of relative humidity and precipitation (nearly 8.4 percentage point), followed by, together with the previous factors, or independently from them, the nearly 1.0 percentage point effect of temperature variation. The moderated decrease of cloud cover only slightly modified the combined effect of the former factors, and the variation of wind force did not have significant effect. The significance and direction of the partial effect of the various climatic factors were also varied. The decrease of relative humidity and especially of temperature moderated, while the increase of precipitation and the decrease of cloud cover increased the probability of accidents.

Table 6. Multivariate regression interrelations of daily variation of accidents (dependent variable) for estimated traffic with daily meteorological variation indicators (independent variables) (Stepwise method), between 1990 and 2010

Model summary*									
					Change statistics				
Model	R	R-squared	Adjusted R-squared	Std. error of the Estimate	R-squared change	F change	df1	df2	Sig. F change
1	0.262[a]	0.069	0.068	0.64266	0.069	106.043	1	1433	0.000
2	0.290[b]	0.084	0.083	0.63761	0.015	23.830	1	1432	0.000
3	0.307[c]	0.094	0.093	0.63424	0.010	16.235	1	1431	0.000
4	0.313[d]	0.098	0.095	0.63327	0.003	5.384	1	1430	0.020

* Dependent variable: daily variation of the number of accidents for estimated traffic

[a] Predictors: (constant), variation of daily mean relative humidity

[b] Predictors: (constant), variation of daily mean relative humidity, variation of daily mean precipitation amount

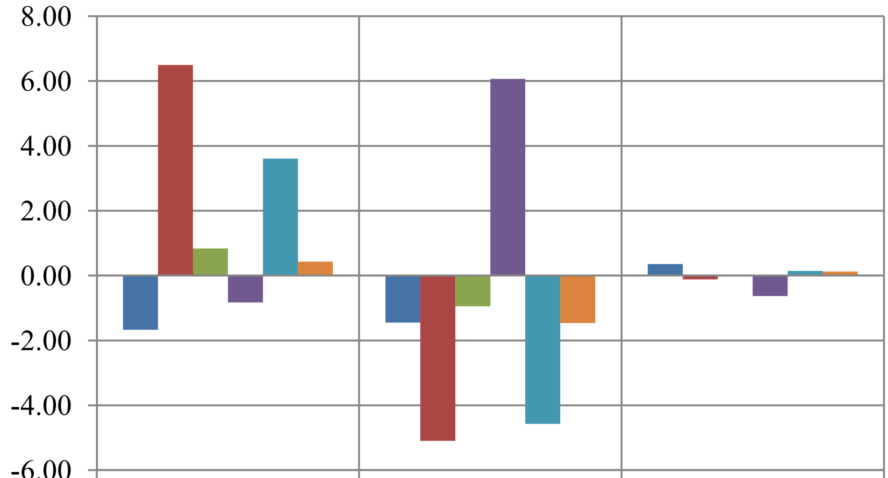
[c] Predictors: (constant), variation of daily mean relative humidity, variation of daily mean precipitation amount, variation of daily mean temperature

[d] Predictors: (constant), variation of daily mean relative humidity, variation of daily mean precipitation amount, variation of daily mean temperature, variation of daily mean cloud cover

In the case of non-extreme – slightly deviating from the mean – meteorological changes, only very weak partial relation prevailed among accident variations and the variations in precipitation, cloud cover, air pressure, and temperature, and there was no significant relation with the variation of relative humidity and wind force.

The mutually neutralizing character of the various meteorological factors played significant role in the weakness of the effect on accident variations, because the accident increasing effect of the rise of temperature and the decrease of air pressure was largely compensated by the accident risk moderating effect of the decrease of precipitation and the growth of cloud cover.

The extreme and non-extreme categories only expressed deviations from the general trend of climatic processes – and not with equal accuracy –, however, they did not reflect the direction of the changes. Consequently, these are not appropriate for the separate examination of interrelations between the development of accidents and the appearance and rising or moderation and disappearance of extremes. Furthermore, they do not offer opportunity to consider and prognosticate the possible consequences on the development of accidents, and in general, on the human and social relations if, in the future, the frequency of appearance and rise, or temporal durability of extreme meteorological conditions should increase compared to non-extreme days and periods. Variation of the daily mean values of the meteorological features by the rate and direction of extremes between 1990 and 2010 is presented in *Fig. 6*.



	Rising extreme	Moderating extreme	Non-extreme variation total
Var. of daily mean temperature [°C]	-1.67	-1.45	0.36
Var. of daily mean precipitation amount [mm]	6.49	-5.09	-0.12
Vari. of daily mean wind speed [m/s]	0.84	-0.95	0.02
Var. of daily mean air pressure [hPa]	-0.83	6.06	-0.63
Var. of daily mean relative humidity [% points]	3.61	-4.57	0.14
Var. of daily mean cloud cover [okta]	0.43	-1.46	0.13

Fig. 6. Variation of the daily mean values of the meteorological features by the rate and direction of extremes between 1990 and 2010.

Regarding the direction of extremes in the various categories among the mean values of examined meteorological indicators – excluding temperature variation –, usually significant and partially symmetric differences were developed. For example, while on days with rising extremes, precipitation increased by a mean of 6.5 mm, relative humidity by 3.6% points, wind force by 0.84 m/s, compared to the previous day, then on days with moderating extremes, precipitation decreased by 5.1 mm, relative humidity by 4.6% points, and wind force by 0.95 m/s. However, the variation of air pressure and cloud cover significantly deviated from the generic trend only in the case of moderating extremes. The air pressure increased rather significantly, and cloud cover decreased. However, temperature usually fell in the course of both rising and moderating extremes.

Applied statistical tests have shown that the most significant difference among the various categories by the direction of the extremes appeared in the precipitation amount variation, but the deviations of air pressure, cloud cover and wind force are also rather characteristic. The differences in the variations of relative humidity, and especially that of temperature, are less relevant than the above-mentioned components.

The appearing and rising meteorological extremes already impacted the increase of accidents by nearly 9.1 percentage. The rise of humidity (in nearly 80 percent), the decrease of temperature, and the strengthening of wind had the most significant impact. The effect of the various meteorological components was not restricted to one-way only. The rise of relative humidity (and of the mostly well correlated precipitation amount) and the increase of wind force impacted the increase of accidents, while the moderation of temperature impacted the decrease of accidents. According to the results of regressive analysis, the effect of temperature decrease slowed the increase of the number of accidents by nearly one third.

In the moderating and disappearing extreme periods the relation between the climatic variations and the variation of accidents is significantly weaker (5.8% R-Square) than in the period of rising extremes, yet still more than twice stronger than in the case of non-extreme variations. It may lay behind the relative weakness of the interrelation that the temporal processes of appearing, rising, and moderating, disappearing are not necessarily of the same length. In moderating extreme periods, the moderation of precipitation amount, closely followed by the moderation of temperature and relative humidity had the most significant impact on the characteristic decrease of accidents. At the same time, the decrease of cloud cover affected the increase of accidents, and as a result, the one-third slower moderation of the number of accidents.

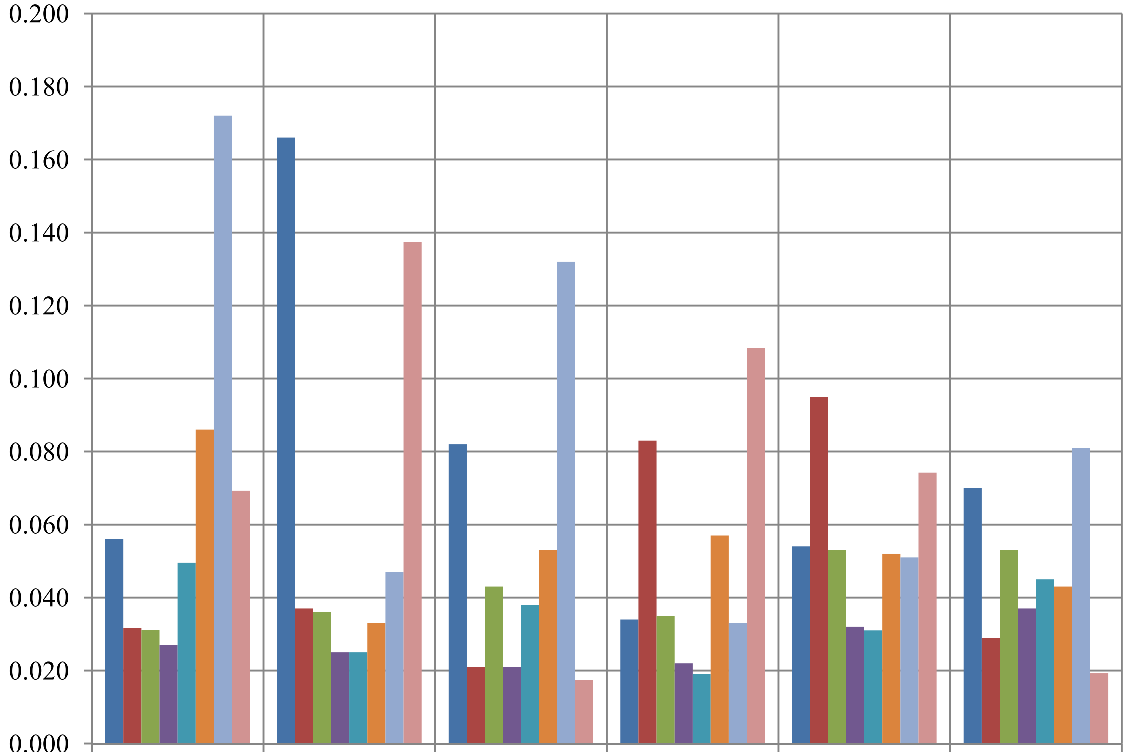
3. Relationship between traffic accidents and key meteorological components

More detailed analyses uncovered significantly stronger relations than in case of categories containing the direction and intensity of meteorological variations rather aggregated regarding the extremes. Especially in the case of the most extreme variation of meteorological conditions, and in the autumn and winter periods, strong correlation was formed with the variation of accidents.

Among the meteorological types of variations came from the 25-element solution, in the case of the group carrying the unfolding of the most extreme variation, the number of accidents increased already in nearly one fifth as the effect of the climatic variations (especially the excessively significant increase of precipitation amount and relative humidity, and decrease of air pressure and temperature) to an outstanding level exceeding the mean value of rising extremity nearly two and a half times. The type is particularly characterized by above the average proportion of summer days with rain, rain shower, and thunderstorm. The number of rainy days is six times, and those with rain shower, and thunderstorm is nearly three times higher than the national average. The climatic determination of accident locations and situations also shows characteristic features. Meteorological variation had particularly significant effect on the development of the frequency of accidents involving slight injuries, hitting pedestrians, oncoming traffic, road bends, and residential area. The effects on accidents involving slight injury nearly ten times, and on accidents involving hitting pedestrians and occurring in road bends over eight times exceeded the general impact.

The strengthening of the interrelation between the intensity of meteorological extremes and the increase of the frequency of accidents can be typically explained by the grouping by direction and intensity of the variation of the analyzed primary meteorological features. In a method identical with multidimensional classifications, the categorization of the various meteorological indicators was also performed with automatic classification technique (K-mean clustering) – in order that the result of classification factually express the spatial distance among the groups as regards their content.

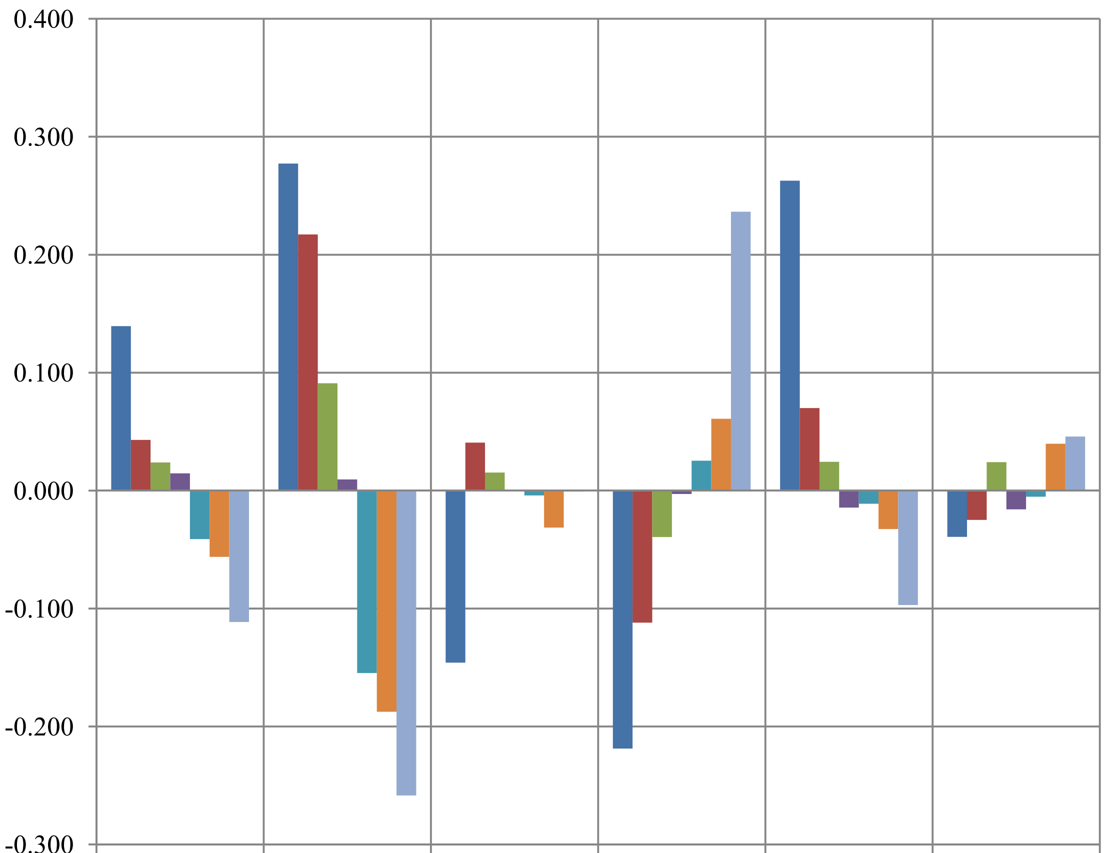
Seven search groups were conventionally determined, therefore because of the differences among the distributions, the number of days significantly differs in the various categories. For example, barely one percent of the days of the examined 21 years was classified into the category of the most intensive precipitation increase, and nearly identically with this proportion, the element number of the most extreme temperature variation (increase and decrease) categories increasing (*Figs. 7* and *8*).



	Var. of daily mean temperature [°C]	Var. of daily mean precipitation amount [mm]	Var. of daily mean wind speed [m/s]	Var. of daily mean air pressure [hPa]	Var. of daily mean relative humidity [% points]	Var. of daily mean cloud cover [okta]
Cluster 1	0.056	0.166	0.082	0.034	0.054	0.070
Cluster 2	0.032	0.037	0.021	0.083	0.095	0.029
Cluster 3	0.031	0.036	0.043	0.035	0.053	0.053
Cluster 4	0.027	0.025	0.021	0.022	0.032	0.037
Cluster 5	0.050	0.025	0.038	0.019	0.031	0.045
Cluster 6	0.086	0.033	0.053	0.057	0.052	0.043
Cluster 7	0.172	0.047	0.132	0.033	0.051	0.081
Total	0.069	0.137	0.017	0.108	0.074	0.019

Fig. 7. Multivariate linear interrelation of daily variation of accidents for traffic with the totality of daily meteorological variations (R-squared) calculated by clusters obtained by automatic classification of certain meteorological variation components.

The offered charts clearly indicate that progressing from the general trend of variations towards the intensification of extremities by an approximately U-shaped curve the effect of the various meteorological factors is increasingly stronger on the development of accidents, and depending on the direction of the variation, increasingly more significant scale variation (rise or decrease) occurred in the number of accidents, as well.



	Var. of daily mean temperature [°C]	Var. of daily mean precipitation amount [mm]	Var. of daily mean wind speed [m/s]	Var. of daily mean air pressure [hPa]	Var. of daily mean relative humidity [% points]	Var. of daily mean cloud cover [okta]
Cluster 1	0.139	0.277	-0.146	-0.219	0.263	-0.039
Cluster 2	0.043	0.217	0.041	-0.112	0.070	-0.025
Cluster 3	0.024	0.091	0.015	-0.039	0.024	0.024
Cluster 4	0.015	0.009	0.000	-0.003	-0.014	-0.016
Cluster 5	-0.041	-0.155	-0.004	0.025	-0.011	-0.005
Cluster 6	-0.056	-0.187	-0.031	0.061	-0.033	0.040
Cluster 7	-0.111	-0.258	-0.001	0.236	-0.097	0.046

Fig. 8. Mean of daily variation of accidents for traffic calculated by clusters obtained by automatic classification of certain meteorological variation components.

In the case of the most extreme categories according to the increase of precipitation amount and the decrease of temperature, the combined effect of all the meteorological factors exceeds four times the average, and more than six times the average of non-extreme days. It can be said of all the above-mentioned categories, that the significant scale variation of accidents (increase in the case of precipitation variation and decrease in the case of temperature variation) was already induced in a proportion of one-sixth by meteorological change or inappropriate accommodation to these.

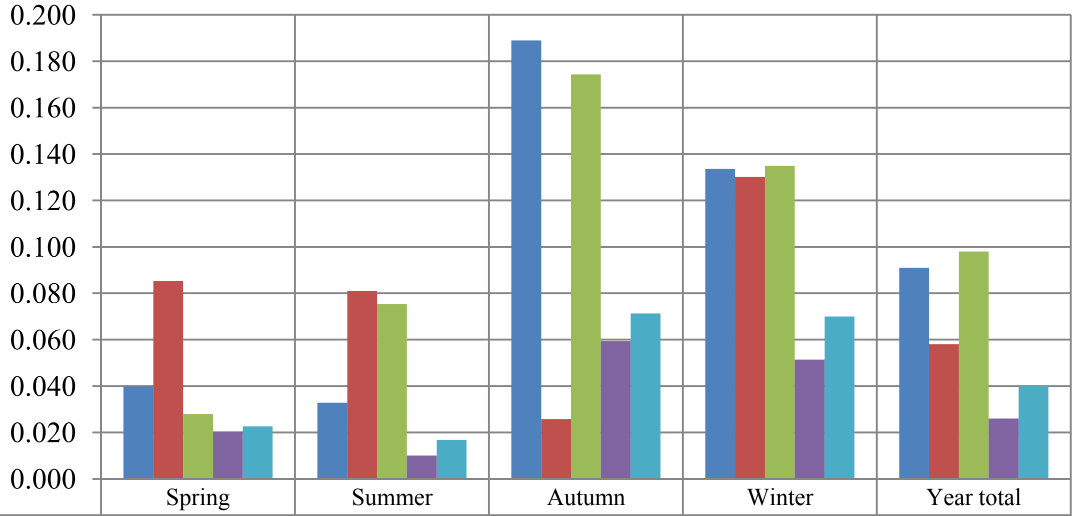
Besides the above mentioned facts, the combined effect of meteorological variation factors was very significant in the most extreme categories as regards wind force strengthening (8.2 and 13.2 percent) but in the frames of both extremes the accident moderating effect became dominant. Furthermore, this effect was significant on the opposing poles of the variation of cloud cover (7, and 8.1 percent determination). The relationship between the variation of accidents and cloud cover – jus as that of air pressure variation – essentially developed inversely as temperature and precipitation variation, because the increase of cloud cover and air pressure amount correlates with the moderation of accidents, while the decrease of these factors correlates with the increase of accidents.

In contrast to the most extreme – mostly containing the rise – categories of air pressure and relative humidity variation, the relationship of one degree less extreme categories was the strongest with the variation of accidents, while accident variation was the most intensive in the most extreme categories. It cannot be excluded, that the use of multidimensional, nonlinear methods or the proper transformation of variants should lead to different results.

4. Relationship between traffic accidents and extreme meteorological variations

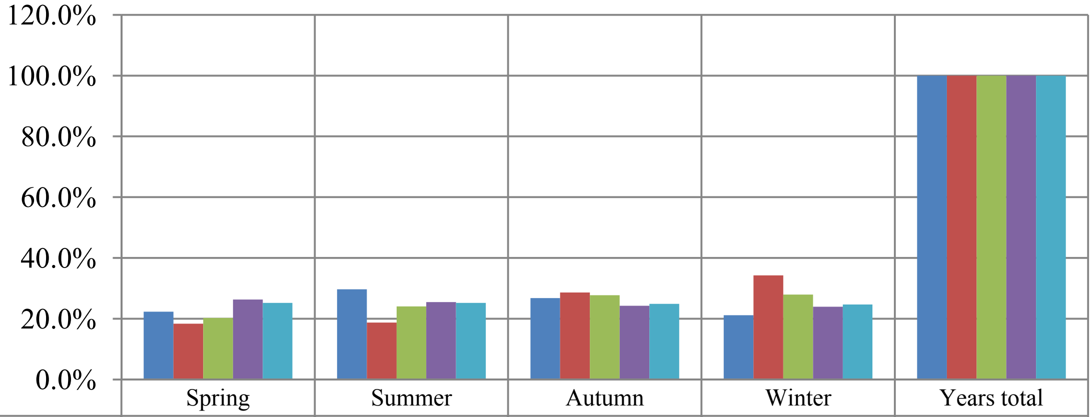
The determination by meteorological variations of accident development changed extraordinarily differently by the seasons. The spring and summer period determination does not reach even half of the average, and only in the period of the moderation of extremes does remarkable relationship manifest itself. In contrast, in the second half-year, meteorological extremes had significant – 17.4 percent in autumn, 13.4 percent in winter – effect on the development of accidents. The linear regressive interrelations (R-squared) between the daily variations by seasons of road traffic accidents involving personal injury and meteorological conditions are shown in *Fig. 9*.

The differences can be partially explained by the unequal distribution of extreme meteorological conditions, according to which, in the second half-year, the frequency of extreme variations characteristically exceeded the average in winter, typically because of the excessive proportion of moderating extremes, while in spring, it significantly fell short of it. The proportion of rising extreme days, on the other hand, exceeded the prorated distribution, especially in summer and autumn. Distribution of daily variations categorized by the type of meteorological extremity across the seasons is presented in *Fig. 10*, while seasonal averages of road accidents involving personal injury for estimated traffic, between 1990 and 2010 can be found in *Fig. 11*.



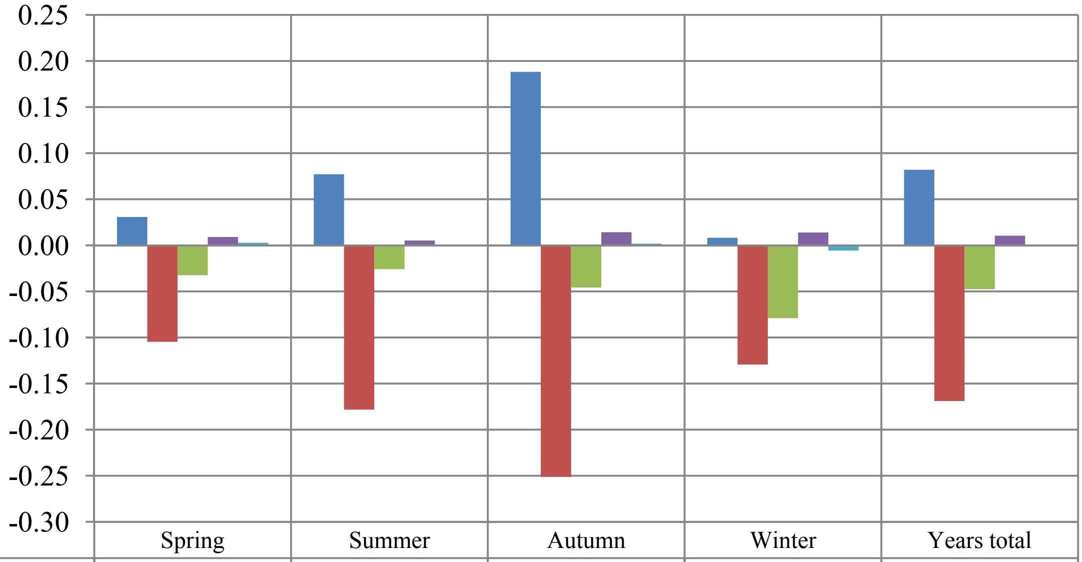
	Spring	Summer	Autumn	Winter	Year total
Rising extreme	0.040	0.033	0.189	0.134	0.091
Moderating extreme	0.085	0.081	0.026	0.130	0.058
Extreme days total	0.028	0.075	0.174	0.135	0.098
Non-extreme days total	0.020	0.010	0.059	0.051	0.026
1990 – 2010 days total	0.023	0.017	0.071	0.070	0.040

Fig. 9. Linear regressive interrelations (R-squared) between the daily variations by seasons of road traffic accidents involving personal injury and meteorological conditions, between 1990 and 2010.



	Spring	Summer	Autumn	Winter	Years total
Rising extreme	22.3%	29.7%	26.8%	21.2%	100.0%
Moderating extreme	18.4%	18.8%	28.6%	34.3%	100.0%
Extreme days total	20.3%	24.0%	27.7%	27.9%	100.0%
Non-extreme days total	26.3%	25.5%	24.3%	24.0%	100.0%
1990 – 2010 days total	25.2%	25.2%	24.9%	24.7%	100.0%

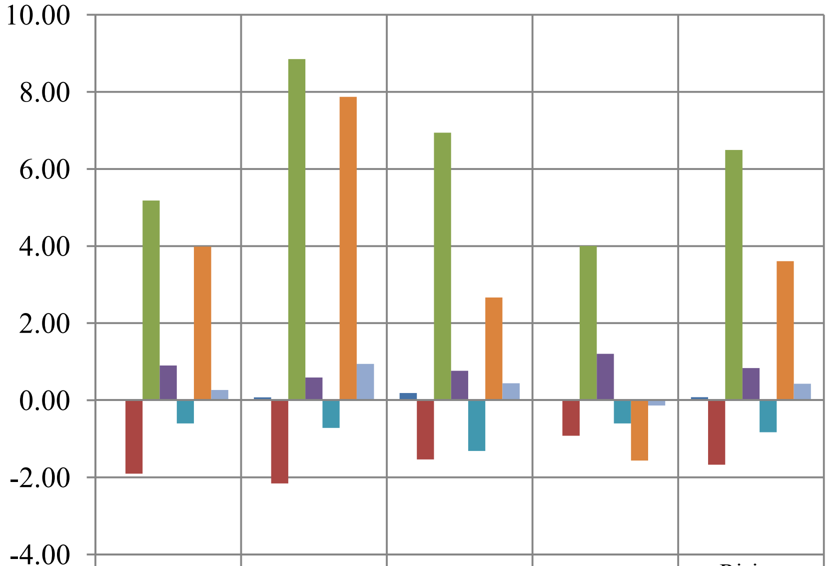
Fig. 10. Distribution of daily variations categorized by the type of meteorological extremes across the seasons.



	Spring	Summer	Autumn	Winter	Years total
Rising extreme	0.03	0.08	0.19	0.01	0.08
Moderating extreme	-0.10	-0.18	-0.25	-0.13	-0.17
Extreme days total	-0.03	-0.03	-0.05	-0.08	-0.05
Non-extreme days total	0.01	0.01	0.01	0.01	0.01
1990 – 2010 days total	0.00	0.00	0.00	-0.01	0.00

Fig. 11. Seasonal averages of road accidents involving personal injury for estimated traffic between 1990 and 2010.

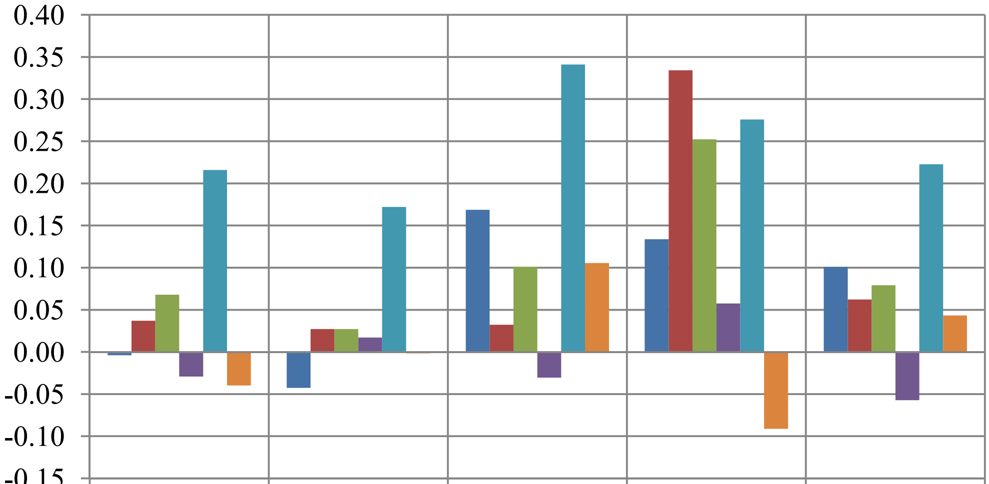
The variation in the number of accidents under unfolding and rising extreme conditions increased in autumn – more than twofold – above the average, and the relationship between accidents and climate variations was the strongest in this season, as well. To an extent nearly one-fifth, the complex impact of climate variation, but especially, the variation of relative humidity (and behind this, the mostly well correlated cloud cover and precipitation amount variation) and the variation of temperature and wind force impacted the development of accidents. The increase of relative humidity and strengthening of wind force impacted the increase of accidents, while the decrease of temperature impacted the decrease of accidents, however, it could only partially slow the increase of accidents. Variation of daily average value of the main meteorological features and the traffic accidents related to estimated traffic density due to previous day in case of rising extremes by seasons is shown in *Fig. 12,* while the development of the calculated standardized Beta coefficient between the daily variations of the traffic accidents with personal injury related to estimated traffic density and the daily variations of the meteorological features in case of rising extremes by seasons is presented in *Fig. 13*.



	Spring	Summer	Autumn	Winter	Rising extremes total
Daily var. of the number of accidents for estimated traffic [accident / hundred thousand vehicles]	0.03	0.08	0.19	0.01	0.08
Var. of daily mean temperature [°C]	-1.90	-2.16	-1.53	-0.92	-1.67
Var. of daily mean precipitation amount [mm]	5.18	8.85	6.94	4.00	6.49
Var. of daily mean wind speed [m/s]	0.90	0.59	0.76	1.21	0.84
Var. of daily mean air pressure [hPa]	-0.60	-0.72	-1.31	-0.60	-0.83
Var. of daily mean relative humidity [% points]	3.99	7.87	2.66	-1.56	3.61
Var.of daily mean cloud cover [okta]	0.27	0.94	0.44	-0.14	0.43

Fig. 12. Variation of daily average value of the main meteorological features and the traffic accidents related to estimated traffic density due to previous day in case of rising extremes by seasons between 1990 and 2010.

Opposed to the autumn periods of rising extremes, the increase of accident numbers in winter reached only one tenth of the average of this type; despite that the totality of meteorological effects directed toward it was relatively significant (13.4 percent). The increase of precipitation amount and the strengthening of wind were especially impacting the increase of accidents, while its decrease was affected characteristically by decreasing relative humidity and decrease of temperature (unlike the rest of the seasons). The moderate increase in the number of accidents is primarily explained by that, in total, in the winter, the intensity of the variation of components of climatic conditions – with the exception of wind force, which increased in a rate exceeding that of the other seasons – was far below the 1990–2010 average of rising extreme variation.



	Spring	Summer	Autumn	Winter	Rising extreme total
Var. of daily mean temperature [°C]	0.00	-0.04	0.17	0.13	0.10
Var. of daily mean precipitation amount [mm]	0.04	0.03	0.03	0.33	0.06
Var. of daily mean wind speed [m/s]	0.07	0.03	0.10	0.25	0.08
Var. of daily mean air pressure [hPa]	-0.03	0.02	-0.03	0.06	-0.06
Var. of daily mean relative humidity [% points]	0.22	0.17	0.34	0.28	0.22
Var. of daily mean cloud cover [okta]	-0.04	0.00	0.11	-0.09	0.04

Fig. 13. Development of the calculated standardized Beta coefficient between the daily variations of the traffic accidents with personal injury related to estimated traffic density and the daily of the meteorological features in case of rising extremes by seasons.

In the spring and summer periods of appearing, rising extremes, only relatively weak (4 and 3.3%, respectively) multivariate linear relationship prevailed between the variation of accidents and climatic conditions; and the change in the number of accidents developed below the average of the category averages, especially in spring, however, still exceeding nearly three times the extent of winter variation. In both seasons, only the increase of relative humidity (or, behind that, the increase of cloud cover and precipitation) had substantial effect on the increase of accidents, yet this effect was much weaker than in autumn or – with different sign – in winter. The different extent increase of accidents was basically brought about by the significantly different intensity of meteorological variations. While springtime variations developed in an extent nearly identical with the annual average of the category, then the relative humidity and cloud cover increased with more than double, and precipitation amount more than one third above the average in the summer period of rising extremes. Only the extent of the increase of wind force fell below the average.

5. *Relationship between traffic accidents and extreme meteorological variations by accident severity, and situation*

Looking at the whole of the 1990–2010 period, the relationship of climatic variations with a more detailed breakdown of accidents – with the development by outcomes involving persons, gravity, accident locations and situations – is rather weak, falling behind the already described overall effect (*Table 7*).

Table 7. Development of multivariate linear regression relationships of the daily variation of meteorological variations and accidents involving personal injury per accident consequences, locations, and situations, and the extremity of meteorological change

Absolute variation from the previous day	**Rising extreme days**	**Moderating extreme days**	**Extreme days total**	**Non-extreme days total**	**Days total in 1990–2010**
	R-squared				
Variation of number of accidents	0.104	0.063	0.097	0.027	0.041
Variation of number of fatal accidents	0.026	0.021	0.015	0.005	0.006
Variation of number of serious accidents	0.062	0.036	0.052	0.013	0.020
Variation of number of slight accidents	0.076	0.045	0.079	0.022	0.032
Variation of number of accidents in residential areas	0.061	0.049	0.049	0.025	0.029
Variation of number of accidents outside residential areas	0.121	0.035	0.111	0.016	0.036
Variation of number of accidents on straight paths	0.074	0.038	0.063	0.014	0.023
Variation of number of accidents in road bends	0.117	0.056	0.120	0.014	0.035
Variation of number of accidents in road crossings	0.040	0.046	0.037	0.028	0.027
Variation of number of accidents in other road sections	0.022		0.010		0.003
Variation of number of accidents due to head-on collision of vehicles	0.160	0.053	0.150	0.027	0.055
Variation of number of accidents due to collision of vehicles travelling in the same direction	0.008	0.050	0.023	0.010	0.012
Variation of number of accidents due to collision of vehicles crossing paths	0.006	0.033	0.013	0.022	0.018
Variation of number of accidents due to slipping, skidding, tipping on road	0.015	0.017	0.012	0.003	0.004
Variation of number of accidents involving hitting pedestrian	0.077	0.013	0.049	0.012	0.021

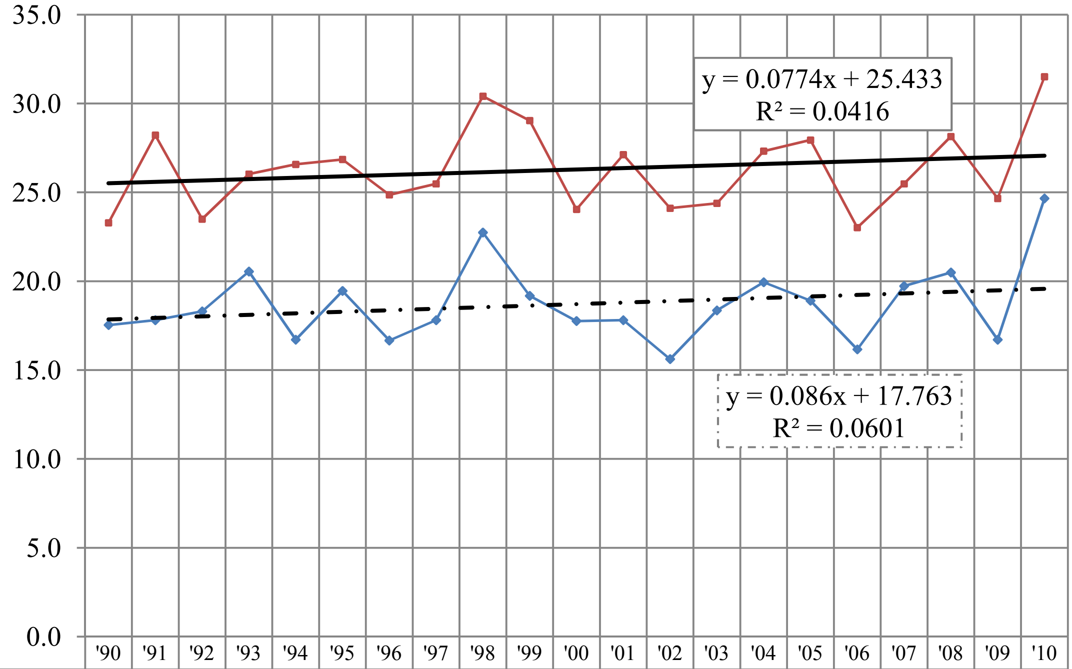
(Note: The table contains only significant statistics.)

Interrelation stronger than the average can we observed only in the case of accidents due to collision of vehicles travelling towards each other ; however, this is not explained by the effects characterized days without meteorological extremes, but by the extremely strong consequences of the appearance and rise of extremes affecting the whole category. The increase in the number of accidents due to the collision of vehicles travelling towards each other in the period of appearing and rising extreme meteorological conditions – beyond all other categories shown in the table – was determined by climatic variations in a proportion of nearly one sixth, or at least developed synchronously with those in this degree. The formation of the interrelation and the significant increase of accidents in scale were primarily (in nearly 90 percent) impacted by the increase of relative humidity of air, and, in the remaining proportion, by the decrease of air pressure.

Besides the above category, meteorological change had particularly significant impact on the increase of accidents outside residential areas and in road bends in an extent exceeding the average of the category of the total appearing and rising extremes (nearly 12 percent). The overall effect was, however, less significant; but in the case of accidents involving hitting pedestrians – in general slight and serious accidents –, on straight paths and in residential areas, the effect of climatic variations in the period of rising extremes exceeds multiple times those prevailing in non-extreme periods. (For example: in the case of hitting pedestrians, nearly six times, and three-four times in the case of accidents involving slight and serious injuries and on straight path, and over twice in case of accidents in residential areas.) Although, in total, the determination of the variation of fatal accidents by climatic variations can be regarded to be modest, it was nearly five times stronger among extreme meteorological conditions than in other periods.

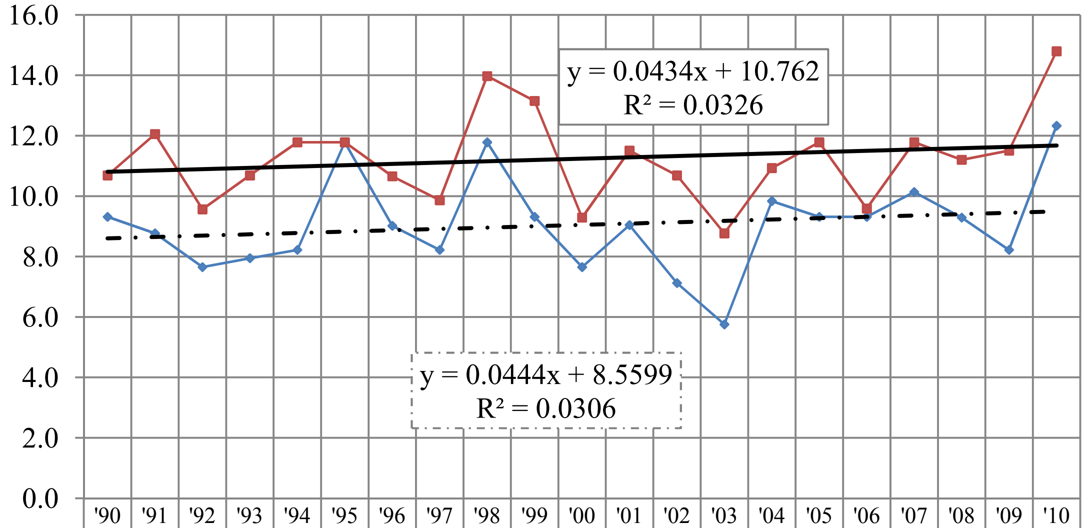
6. Future expected tendencies between traffic accidents and key meteorological variations

The time series data of the endeavor to differentiate extreme and non-extreme meteorological changes show, that between 1990 and 2010 the climatic variations became somewhat more extreme. This is supported by the data expressing the annual proportions of extreme, and appearing and rising extreme days, and the linear trends calculated on their basis. The relatively detailed classification and the reclassified – giving a broader sense to extremity – categorization essentially led to the same result. According to both approaches, the linear trend of extremity and rising extremes – in spite of fluctuations – took a decidedly upward direction. Proportion of extreme days as well as that of rising extreme days is shown in *Figs. 14* and *15*.



	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10
Extreme days total, analyzed	17.5	17.8	18.3	20.5	16.7	19.5	16.7	17.8	22.7	19.2	17.8	17.8	15.6	18.4	19.9	18.9	16.2	19.7	20.5	16.7	24.7
Extreme days total, extended	23.3	28.2	23.5	26.0	26.6	26.8	24.9	25.5	30.4	29.0	24.0	27.1	24.1	24.4	27.3	27.9	23.0	25.5	28.1	24.7	31.5

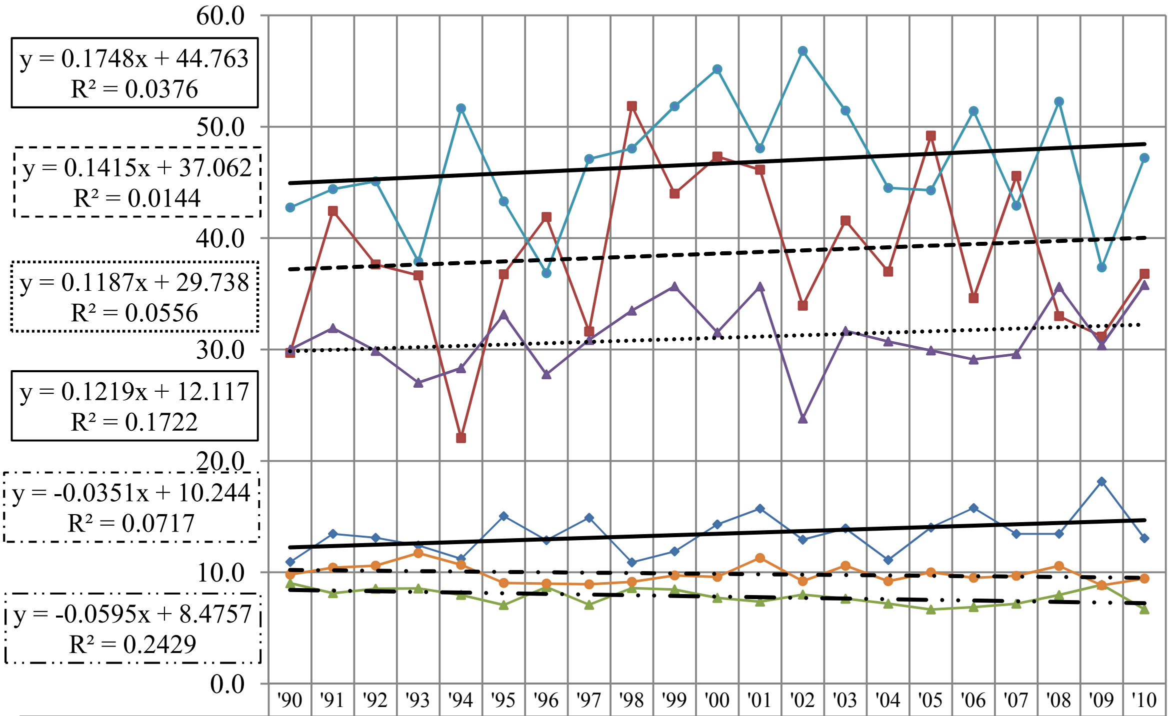
Fig. 14. Proportion of extreme days between 1990 and 2010 (%).



	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10
Rising extreme, analyzed	9.3	8.8	7.7	7.9	8.2	11.8	9.0	8.2	11.8	9.3	7.7	9.0	7.1	5.8	9.8	9.3	9.3	10.1	9.3	8.2	12.3
Rising extreme, extended	10.7	12.1	9.6	10.7	11.8	11.8	10.7	9.9	14.0	13.2	9.3	11.5	10.7	8.8	10.9	11.8	9.6	11.8	11.2	11.5	14.8

Fig. 15. Proportion of rising extreme days between 1990 and 2010 (%).

The variability trends of the various meteorological features mostly support the picture painted by the typologies. The linear trends of temperature, precipitation, air pressure, and relative humidity – although to varying extent – refer to the rising of extremes, while that of wind force and cloud cover to moderating extremes. Absolute deviation (range) by the year of the daily variation of the meteorological indicators between 1990 and 2010 is presented in *Fig. 16*.



	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10
Var. of daily mean temperature [°C]	10.9	13.5	13.1	12.4	11.2	15.0	12.9	14.9	10.9	11.9	14.3	15.7	12.9	13.9	11.1	14.0	15.8	13.4	13.5	18.2	13.1
Var. of daily mean precipitation amount [mm]	29.7	42.4	37.6	36.7	22.1	36.8	41.9	31.6	51.9	44.0	47.3	46.1	33.9	41.6	37.0	49.2	34.6	45.6	33.0	31.2	36.8
Var. of daily mean wind speed [m/s]	9.0	8.1	8.5	8.6	8.0	7.1	8.7	7.1	8.6	8.5	7.7	7.4	8.0	7.6	7.2	6.7	6.9	7.2	8.0	8.9	6.7
Var. of daily mean air pressure [hPa]	30.0	31.9	29.9	27.0	28.3	33.1	27.8	30.9	33.5	35.7	31.5	35.7	23.8	31.7	30.7	29.9	29.1	29.6	35.6	30.4	35.8
Var. of daily mean relative humidity [% points]	42.8	44.4	45.1	37.9	51.7	43.3	36.9	47.1	48.0	51.8	55.2	48.1	56.8	51.5	44.5	44.3	51.4	42.9	52.3	37.4	47.2
Var. of daily mean cloud cover [okta]	9.8	10.4	10.6	11.7	10.7	9.1	9.0	8.9	9.2	9.7	9.6	11.3	9.2	10.6	9.2	10.0	9.5	9.7	10.6	8.8	9.4

Fig. 16. Absolute deviation (range) by the year of the daily variation of the meteorological indicators between 1990 and 2010.

On the basis of interrelationships seen between the slight extremization of meteorological variations, furthermore the extreme climatic variations and the variation of traffic accidents involving personal injury, it could be assumed that approaching our days, the connection would be further strengthened. This hypothesis, however, was supported neither by the totality of meteorological variations, nor the statistical analyses of the various extremity categories.

According to the linear regression analysis of the annual (and three-year period) relationships of accident and meteorological variations, the correlation essentially did not change between 1990 and 2010, however, compared to 1993, the correlation weakened, and there were significant fluctuations within the period. (Note, that statistically not significant relations are not shown in the diagrams.) Results are shown in *Figs. 17, 18,* and *19*.

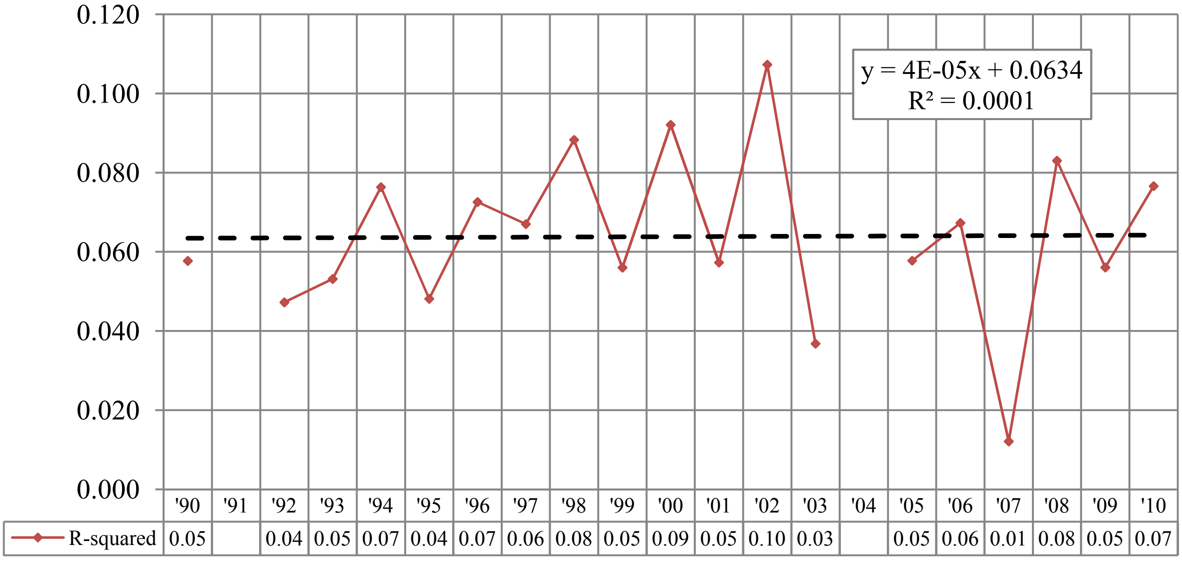


Fig. 17. The multivariate linear regression analysis interrelation (R-squared) calculated among the daily variation of traffic accidents involving personal injury with the daily variation of analyzed meteorological characteristics between years 1990 and 2010.

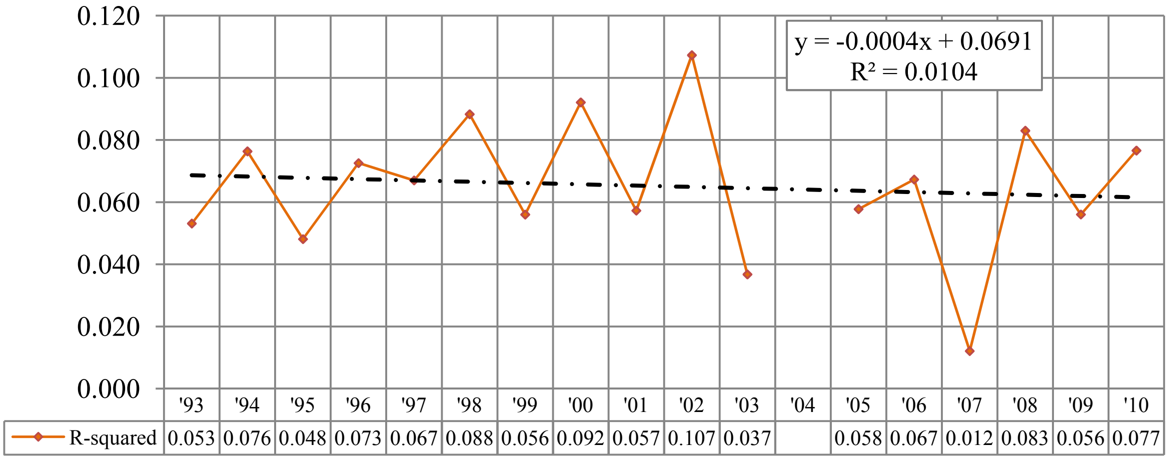
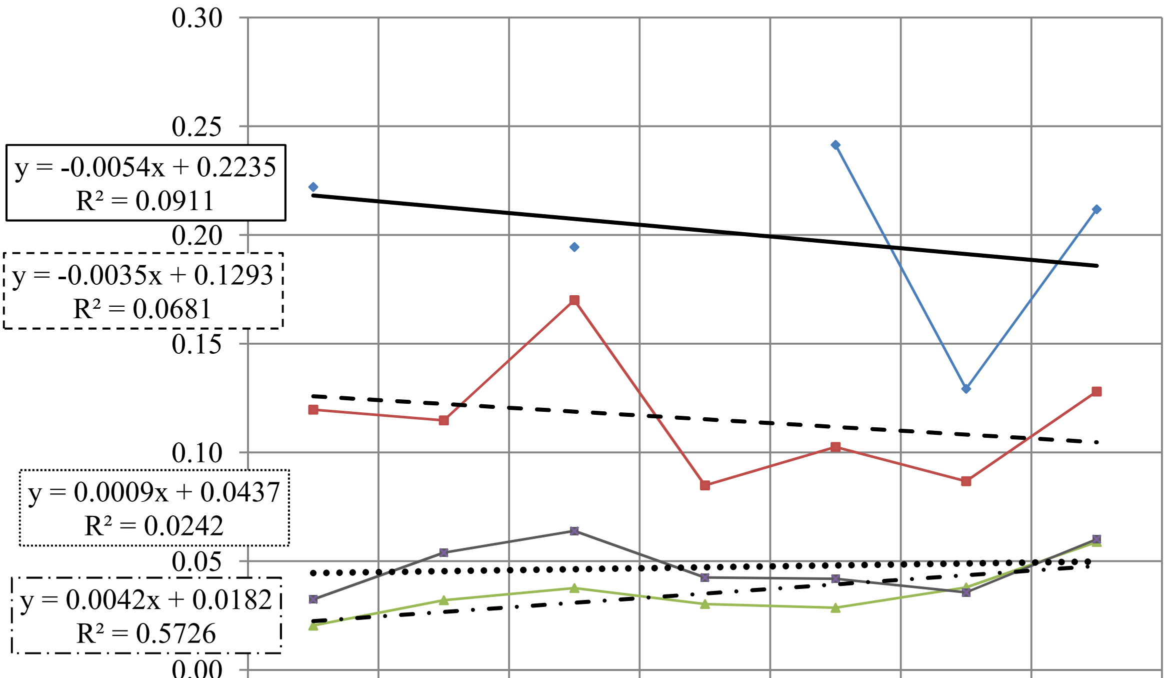


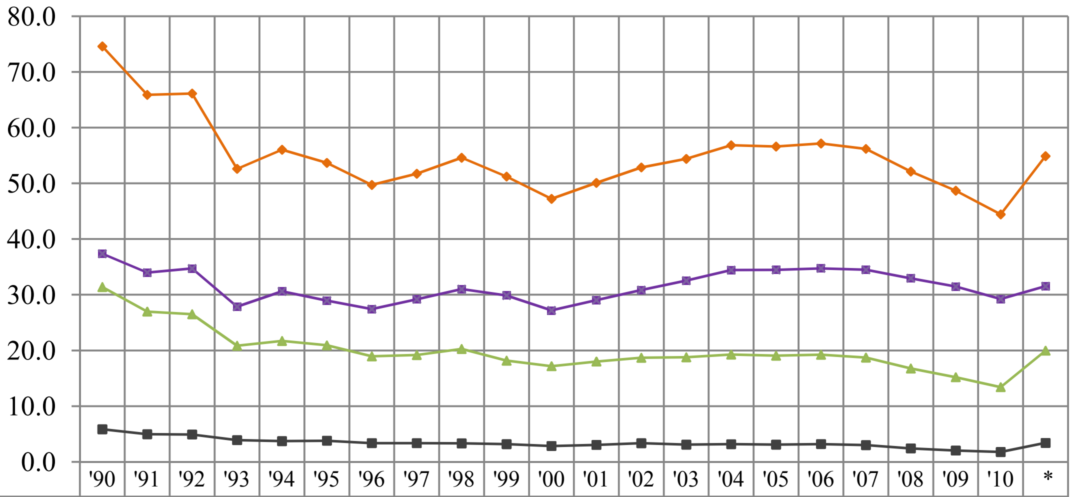
Fig. 18. The multivariate linear regression analysis interrelation (R-squared) calculated among the daily variation of traffic accidents involving personal injury with the daily variation of analyzed meteorological characteristics between years 1993 and 2010.



	1990 - 1992	1993 - 1995	1996 - 1998	1999 - 2001	2002 - 2004	2005 - 2007	2008 - 2010
Rising extremes	0.22		0.19		0.24	0.13	0.21
Extreme days total	0.12	0.11	0.17	0.08	0.10	0.09	0.13
Non-extreme days	0.02	0.03	0.04	0.03	0.03	0.04	0.06
Days total	0.03	0.05	0.06	0.04	0.04	0.04	0.06

Fig. 19. The multivariate linear regression interrelations (R-squared) calculated among the daily variation of traffic accidents involving personal injury with the daily variation of analyzed meteorological features, between 1990 and 2010, in three years breakdown.

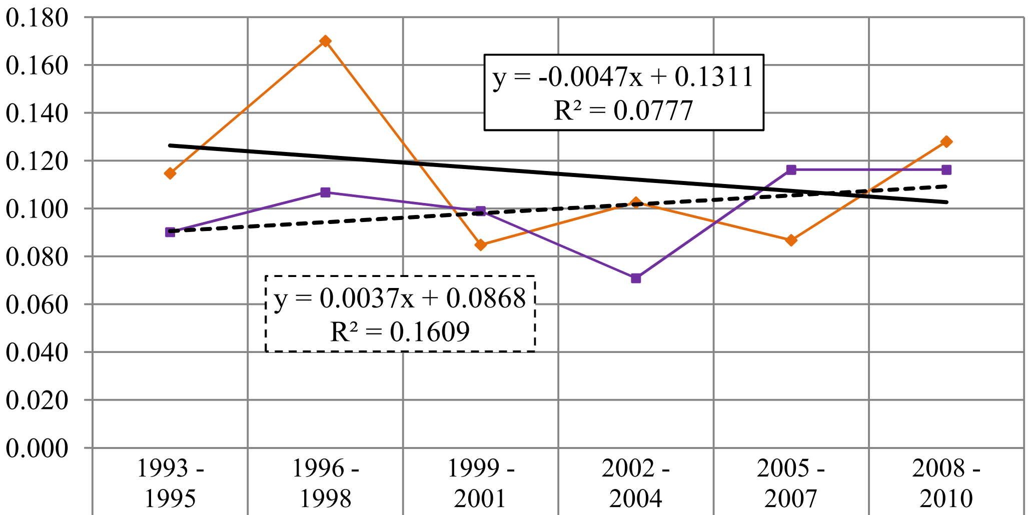
Presumably, the weakness and weakening of relationships can primarily be explained by the rather significant moderation of total traffic accidents involving personal injury, by their relatively hectic development, and by economic processes and regulatory environment affecting the above. In 2010, the number of accidents was nearly forty percent lower than in 1990, primarily on account of the decrease of fatal and serious accidents. At the same time, the number of slight accidents fell only by 21.8% compared to 1990; what's more, between 1993 and 2010, it moreover even increased. On account of the above circumstances, it seemed appropriate to extend the analysis to slight accident data between 1993 and 2010. The result of this shows that interrelation between extreme climatic variations and the variation of traffic accidents involving slight personal injury strengthened in the analyzed epoch (*Figs. 20* and *21*).



	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	*
Number of accidents	74.6	65.9	66.1	52.6	56.0	53.7	49.7	51.7	54.6	51.2	47.2	50.1	52.9	54.4	56.8	56.6	57.2	56.2	52.1	48.7	44.4	54.9
Number of fatal accidents	5.8	5.0	4.9	3.9	3.7	3.8	3.4	3.4	3.3	3.2	2.8	3.0	3.3	3.1	3.2	3.1	3.2	3.0	2.4	2.0	1.8	3.4
Number of serious injury accidents	31.4	27.0	26.5	20.8	21.7	20.9	18.9	19.2	20.3	18.2	17.2	18.0	18.7	18.8	19.3	19.1	19.2	18.7	16.8	15.2	13.4	20.0
Number of slight injury accidents	37.4	34.0	34.7	27.9	30.6	29.0	27.4	29.2	31.0	29.9	27.2	29.0	30.8	32.5	34.4	34.5	34.7	34.5	33.0	31.5	29.2	31.5

*1991–2010 annual average

Fig. 20. Road traffic accidents involving personal injury between 1900 and 2010.



	1993 - 1995	1996 - 1998	1999 - 2001	2002 - 2004	2005 - 2007	2008 - 2010
Daily var. of accident numbers	0.115	0.170	0.085	0.103	0.087	0.128
Daily var.of slight accident numbers	0.090	0.107	0.099	0.071	0.116	0.116

Fig. 21. Three-year multivariate linear interrelations of day-to-day variation of accidents and meteorological conditions between 1993 and 2010 (R-squared) in case of extreme variation.

Naturally, the above described results will provide little guidance to the prognosticability of future developments; however, on the basis of the analysis results, it can be said that the significant future rise of extreme meteorological conditions, and, possibly as a result, the appearing and rising climate change will have significant effect on the development, on the number of accidents, or on the deceleration of the rate of moderation, and, in general, on the development of social relations, which are generally relatively well represented by accident conditions.

7. Conclusions

Compared to other economically and socially important sectors such as energy, water resources, agriculture, and human health (*Törő et al.*, 2010), the assessment of the potential impacts of climate change on transport and road accidents is an area with very limited investigations so far. The increased demand for personal mobility, the dependence on reliable movement of goods and components in the supply chain, and the observed disruption effect of the weather (*Koetse* and *Rietveld*, 2009) make the study of current and future transport resilience essential.

The investigations presented above might provide a potential guidance to the expectation of future developments in the forthcoming decades. On the basis of the results, it can probably be said that the expected increase in the number and intensity of extreme meteorological conditions can have a visible effect on the increase of the number of road accidents. The problem is rather complex, since the future climate change is expected to influence several layers of the social conditions as well, which is also going to be reflected in the road accident conditions.

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